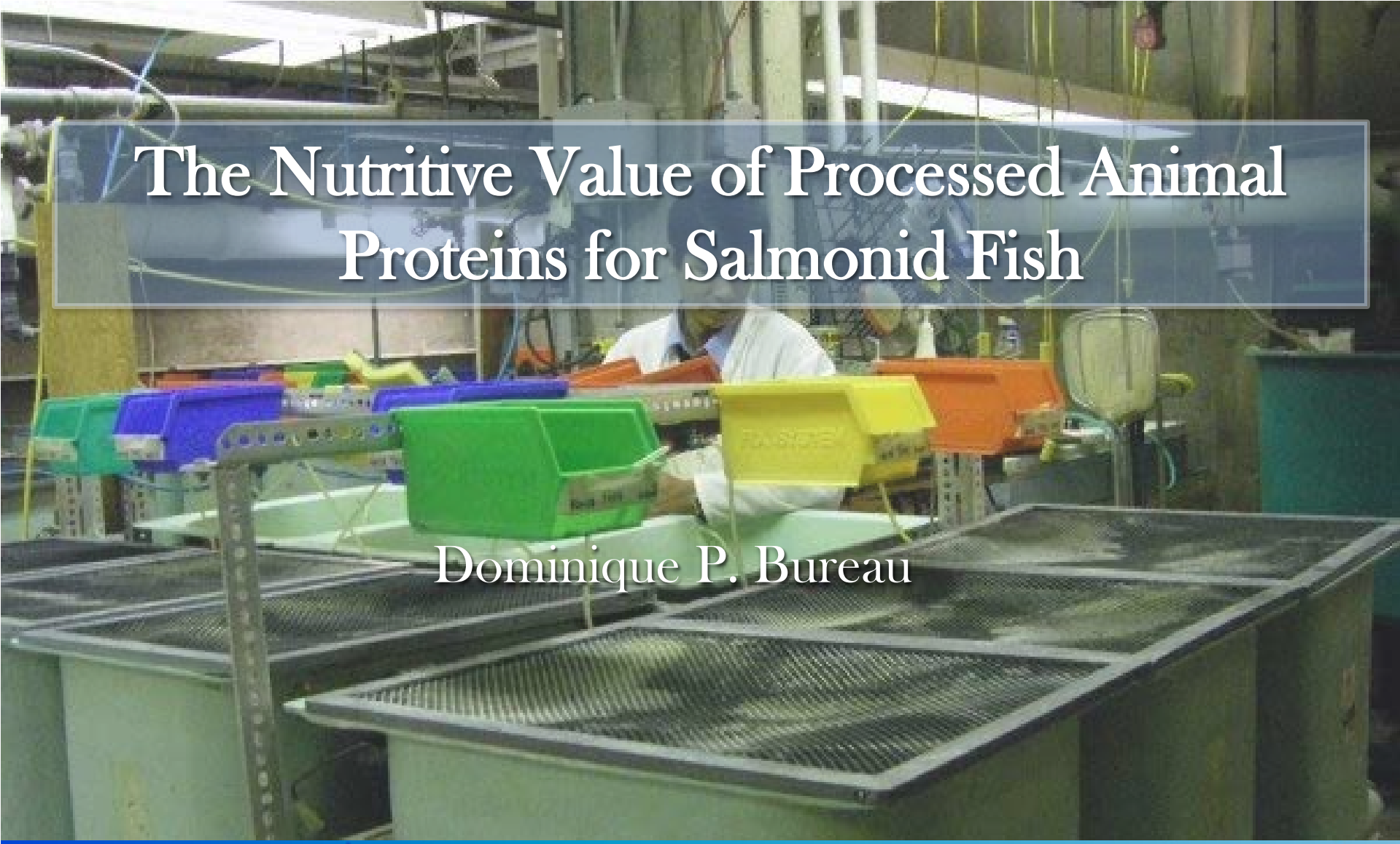
The Nutritive Value of Processed Animal Proteins for Salmonid Fish

Dominique P. Bureau



Fish Nutrition Research Lab

Dept. Animal and Poultry Science | Ontario Ministry of
University of Guelph | Natural Resources

Common feed ingredients used in aquaculture feeds in Europe
Not that many options…

Marine raw materials


Fish meal standard


Fish meal LT


Fish oil

Vegetable raw materials


Soy protein


Wheat gluten


Canola meal


Canola oil


Corn gluten meal


Soybean meal


Wheat


Sunflower meal

Other ingredients


Feed additives


Krill meal


Poultry meal


Hemoglobin meal


Vitamins & minerals

(adapted from **Niels Alsted**/Biomar - 2011)

North & South American and Asian Perspectives

Processed animal protein ingredients (blood meal, feather meal, meat and bone meal, and poultry by-products meal) compare favorably cost-wise with many other types of protein sources commonly used in fish feeds.

They are good sources of several keys nutrients, such as essential amino acids, phosphorus, and various minor nutrients (micro-minerals, phospholipids, cholesterol, etc.)

Accurately characterizing the nutritive value of the different types and batches/lots of processed animal proteins available on the market is essential to optimize their use in feeds.

Comparison of the Cost of Different Protein Sources

Feedstuffs	Crude Protein %	Price* USD $/tonne	Apparent Digestibility of Protein %	Price $/tonne Crude Protein	Price $/tonne Digestible protein
Fish Meal	65	1700	90	2,615	2,906
Rapeseed (Canola) Meal	38	400	87	1,053	1,210
Corn Gluten Meal	60	600	93	1,000	1,075
Soybean Meal, 48% USA Rotterdam	48	550	89	1,146	1,287
DDGS, USA	35	280	80	800	1,000
Poultry By-Products Meal, USA	57	530	87	930	1,069
Meat and Bone Meal, USA	50	460	85	920	1,082
Feather Meal, USA	80	630	75	788	1,050

* Source: Hammersmith Marketing Ltd - Grain Trading
WEEKLY FEED GRAIN AND PROTEIN REPORT May 18, 2013

Essential Amino Acid Composition of some Processed Animal Proteins

Ingredients	ARG	HIS	ILE	LEU	LYS	MET	PHE	THR	VAL	TRP
	% DM									
Fish meal, herring	4.8	1.5	2.6	4.7	3.9	1.4	2.7	2.7	3.3	1.1
Meat and bone meal	3.4	1.1	1.5	3.2	2.5	0.9	1.8	1.9	2.1	0.4
Poultry by-prod. meal, low ash	5.1	1.6	2.4	5.1	4.3	1.6	2.9	3.1	3.2	0.7
Poultry by-prod. meal, high ash	5.0	1.5	2.4	4.9	4.2	1.5	2.7	2.9	3.2	0.7
Hydrolyzed feather meal	6.4	0.7	4.3	7.2	2.7	0.6	4.3	4.2	6.5	0.6
Spray-dried blood meal	3.6	6.7	0.3	11.5	7.0	0.8	6.1	2.8	6.6	1.3
Porcine meat meal	5.2	1.3	2.4	4.2	3.8	1.2	2.4	2.3	3.0	0.4[b]

Historical Note (circa 1995)

1970-95 : Review of literature and discussions with aquaculture feed industry personnel and researchers indicate general lack of trust in nutritive value of animal proteins for fish

Why?

Digestibility values of certain animal products reported in the reference literature (up to 1993) were very low, making these ingredients uninteresting to use.

USA National Research Council (1993):

Apparent digestibility coefficient (ADC) of protein

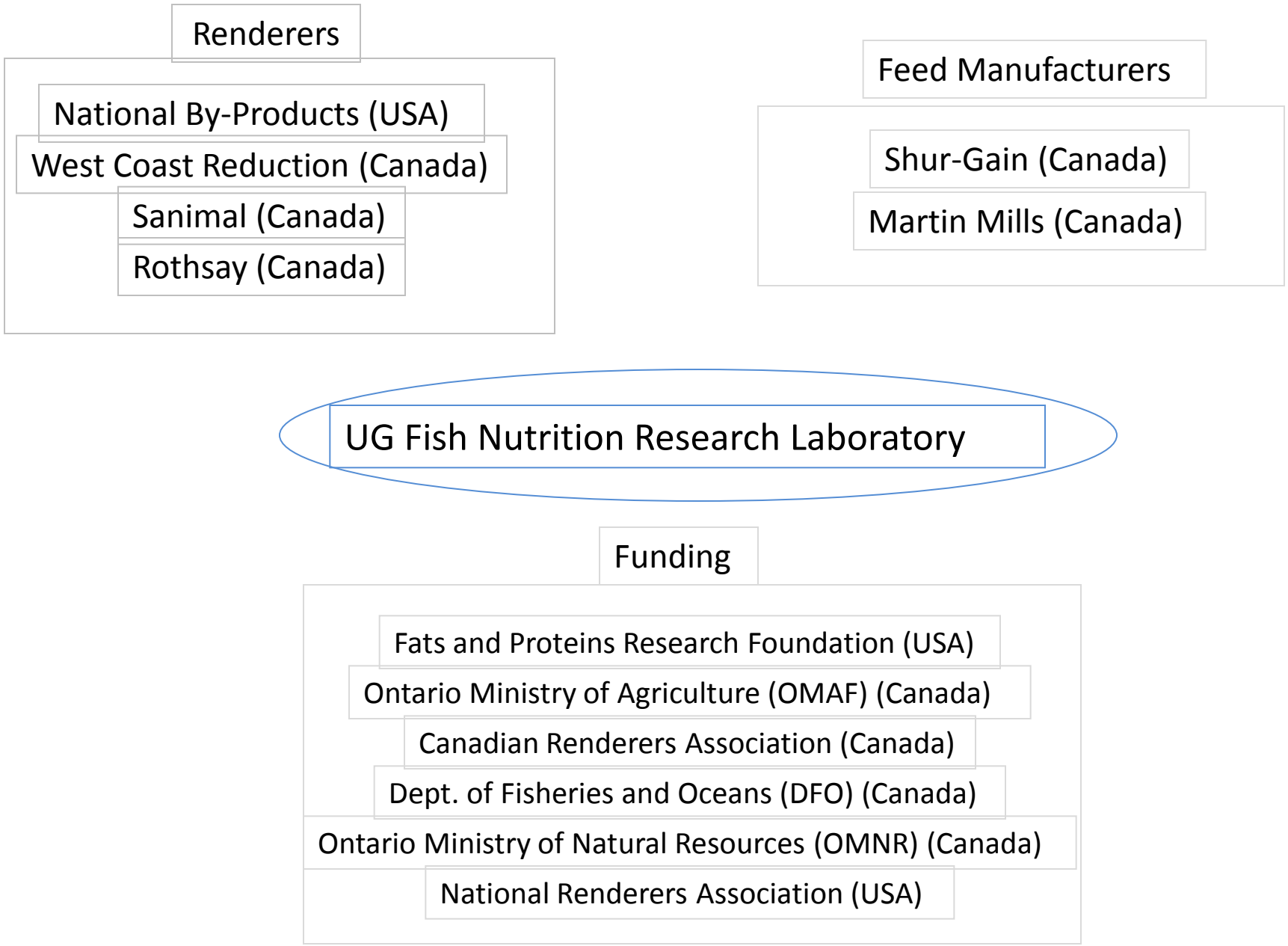
Feather meal	58%
Poultry meal	68%

Data from
Cho & Slinger (1979)
(U of Guelph)

Are these old Guelph reference values realistic?

Characterizing the Nutritive Value of Processed Animal Proteins

Informal Research Partnership (1994-2004)



Processed Animal Proteins Sourced from Different Rendering Plants

Table 1
Manufacturing characteristics of the rendered animal protein ingredients used in the digestibility trial #1 and #2 (as provided by the manufacturers)

Feather meal	Raw material	Hydrolysis[a]	Drying	Size
Feather meal 1	chicken and turkey feathers, hog hair	30 min, 276 kPa	disc dryer (1 h)	2.38 mm
Feather meal 2	chicken, turkey and duck feathers	5 min, 448 kPa	disc dryer (1 h, 93°C)	2.00 mm
Feather meal 3	chicken and turkey feathers, hog hair	40 min, 276 kPa	ring dryer	–
Feather meal 4	chicken and turkey feathers, hog hair	40 min, 276 kPa	indirect steam (steam-tube dryer)	–

Meat and bone meal	Raw material	Cooking[a]	System
Meat and bone meal 1	30% pork offal, 30% beef offal, 20% shop fats and bones, 10% poultry, 10% other material	125–130°C, 20–30 min, 17–34 kPa	Carver–Greenfield falling film evaporator (Stord slurry)
Meat and bone meal 2	Same as meat and bone meal 1	Same as meat and bone meal 1	Same as meat and bone meal 1 but air classification of final product to reduce ash content (performed on experimental scale)
Meat and bone meal 3	pork, beef, other (1%)	133°C, 30–40 min 54 kPa (final stage)	Dupps falling fill evaporator (Dupps slurry)
Meat and bone meal 4	beef (80%), pork (20%)	128°C, 20–30 min 17–34 kPa	Carver–Greenfield falling film evaporator (Stord slurry)
Meat and bone meal 5	pork, poultry, beef	132–138°C, 60 min	Stord continuous system
Meat and bone meal 6	pork, poultry, beef	127–132°C, 25 min vacuum during first stage	Carver–Greenfield falling film evaporator (Stord slurry)

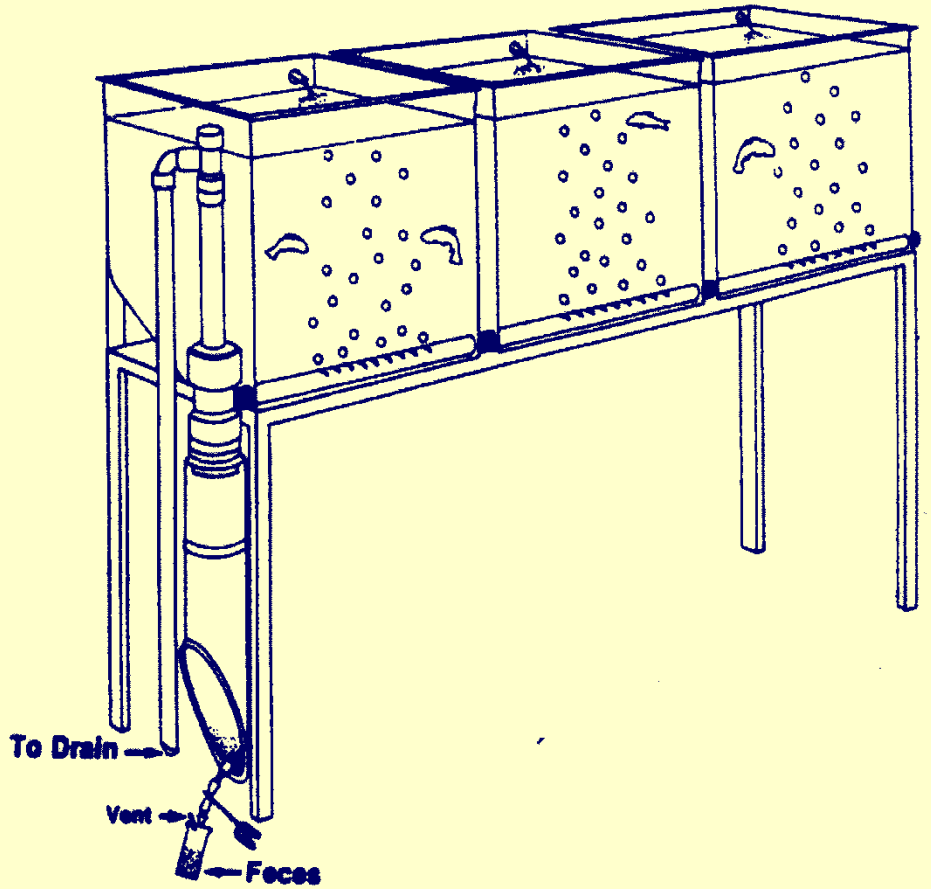
Poultry by-product meal	Raw material	Cooking[a]	System
Poultry by-product meal 1	70% offal, 30% feet, legs and meat	138°C, 30 min	Dupps 260J Equacooker
Poultry by-product meal 2	88% chicken, 10% turkey, 2% duck and game birds	132°C, 30–40 min 54 kPa (final stage)	Dupps falling film evaporator (Dupps slurry)

Blood meal	Raw material	Coagulation	Drying
Blood meal 1	Whole blood	Steam injection coagulation (2 stages) — decanter	Rotoplate, 93°C
Blood meal 2	Whole blood	Steam injection coagulation — decanter	Ring dryer

[a]Normal atmospheric pressure = 101.3 kPa. Pressures of 17, 34, 54 kPa are the equivalent of vacuums of 25, 20 and 14 in. mercury, respectively. Pressures of 276 and 448 kPa are the equivalent of 40 and 65 psi, respectively.

UG/OMNR Fish Nutrition Research Laboratory

The Guelph System (Cho et al., 1982)



Guelph Digestibility System

Equation - Digestibility

$$ADC_{ingr} = ADC_{test} + ((1-s)D_{ref}/sD_{ingr})\ (ADC_{test}-ADC_{ref})$$

ADC_{ingr}=	Apparent digestibility coefficient test diet
ADC_{ref}=	Apparent digestibility coefficient reference diet
D_{ref}=	Nutrient content of reference diet
D_{ingr}=	Nutrient content of ingredient
s =	Level of incorporation of ingredient in test diet (e.g. 30%)

Apparent Digestibility of Processed Animal Proteins in the late 1990s

Ingredients	Apparent Digestibility Coefficients (%) DM	CP	GE
Trial #1			
Feather meal 1	82	81	80
Feather meal 2	80	81	78
Feather meal 3	79	81	76
Feather meal 4	84	87	80
Meat and bone meal 1	61	83	68
Meat and bone meal 2	72	87	73
Trial #2			
Meat and bone meal 3	72	88	82
Meat and bone meal 4	66	87	76
Meat and bone meal 5	70	88	82
Meat and bone meal 6	70	89	83
Trial #3			
Feather meal 5	86	88	84
Feather meal 6	83	86	81
Feather meal 7	83	88	83
Meat and bone meal 7	78	92	86
Meat and bone meal 8	72	89	81
Meat and bone meal 9	69	88	80

Apparent Digestibility of Feather Meals

	ADC	
Guelph System	**Protein**	**Energy**
Cho et al. (1982)	58%	70%
Sugiura et al. (1998)	82-84%	N/A
Bureau (1999)	81-87%	76-80%
Stripping	HCl hydrolyzed feather meal	
Pfeffer et al. (1995)	83%	81%

Data obtained using the same facilities and methodology. There is value in using standard methodological approaches consistently over many years.

Apparent Digestibility of Poultry By-Products Meal

Guelph System	ADC	
	Protein	Energy
Cho et al. (1982)	68%	71%
Hajen et al. (1993)	74-85%	65-72%
Sugiura et al. (1998)	96%	N/A
Bureau et al. (1999)	87-91%	77-92%

Data obtained using the same facilities and methodology

Apparent digestibility coefficients of nutrients and energy of some ingredients

	Apparent Digestibility Coefficient (%)				
Ingredient	**DM**	**CP**	**Lipid**	**GE**	**P**
Poultry meal	70 ±4	79 ±3	90 ±7	77 ±2	29 ±23
Turkey meal	76 ±5	84 ±2	92 ±3	85 ±4	26 ±14
Feather meal	71 ±2	69 ±5	75 ±13	67 ±2	74 ±24
Porcine meal	75 ±6	85 ±1	90 ±8	82 ±5	30 ±6
Canola meal	74 ±4	87 ±3	93 ±3	76 ±3	46 ±8
Sunflower meal	61 ±5	95 ±3	-	64 ±4	35 ±6
Corn protein concentrate	74 ±3	77 ±5	70 ±14	69 ±1	61 ±5

Digestible nutrient (%) and digestible energy (kJ/g) contents of some ingredients (DM basis)

Ingredients	DDM %	DCP %	DLipid %	DAsh %	DE kJ/g	DPh %
Poultry meal	68.4	50.5	11.9	6.9	15.9	1.0
Turkey meal	71.4	56.6	11.7	8.9	16.9	0.9
Feather meal	67.2	62.4	5.0	2.3	16.3	0.4
Porcine meal	73.6	56.8	12.3	7.1	17.5	1.2
Canola meal	67.7	28.1	11.7	4.2	16.5	0.4
Sunflower meal	55.0	38.2	-	3.3	12.5	0.4
Corn protein concentrate	68.1	65.9	2.6	1.0	17.3	1.3

Performance of rainbow trout fed test diets during a digestibility trial

		Parameter			
Period	**Treatment**	**IBW (g)**	**FBW (g)**	**TGC (%)**	**FE (gain:feed)**
1	Diet 1- Reference	76.5	145.6	0.340	1.40
	Diet 2- Poultry meal	81.6	158.6	0.360	1.40
	Diet 3- Turkey meal	68.4	127.6	0.316	1.45
	Diet 4- Feather meal	74.1	142.4	0.342	1.39
	Diet 5- Porcine meal	77.9	153.9	0.360	1.51
	Diet 6- Canola meal	73.5	139.9	0.340	1.32
	Diet 7- Sunflower meal	74.5	139.3	0.330	1.25
	Diet 8- Corn protein conc.	76.1	145.9	0.340	1.49
2	Diet 1- Reference	157.6	213.9	0.341	1.27
	Diet 2- Poultry meal	130.5	178.9	0.331	1.23
	Diet 3- Turkey meal	141.2	192.3	0.333	1.22
	Diet 4- Feather meal	154.4	206.8	0.323	1.22
	Diet 5- Porcine meal	138.8	185.1	0.306	1.22
	Diet 6- Canola meal	145.4	200.7	0.352	1.17
	Diet 7- Sunflower meal	146.2	197.5	0.326	1.17
	Diet 8- Corn protein conc.	149.7	190.1	0.259	1.09

Nutrient Composition of Different Fish Meals and Poultry by-Products Meals

	Fish meal		Poultry by-Products Meal		
Composition	**Herring**	**Menhaden**	**Feed-grade**	**Prime**	**Refined**
Dry matter, %	93	91	97	96	97
Crude Protein, %	71	61	62	66	70
Crude fat, %	9	9	11	8	10
Ash, %	12	22	15	15	11
Phosphorus, %	2.4	3.1	2.6	2.8	2.0
Lysine, %	5.4	4.2	3.7	3.7	4.6
Methionine, %	1.8	1.5	1.2	1.3	1.5
Histidine, %	2.2	1.2	1.4	1.2	1.5
Threonine, %	3.1	2.4	2.5	2.4	3.0

Fish meal is not fish meal and poultry by-products meal is not poultry by-products meal. These are generic names that regroup ingredients that can be widely different.

Cheng and Hardy (2002)

Feeds Based on Herring Meal, Menhaden Meal or Poultry Meal

	1	2	3	4	5	6
Ingredients	**MM10**	**MM20**	**HM10**	**HM20**	**NFM**	**Profishent**
Fish meal, herring	-	-	100	200	-	+
Fish meal, menhaden	100	200	-	-	-	-
Poultry by-prod. meal	300	200	300	200	400	+
Soybean meal	90	80	120	120	70	+
Corn gluten meal	150	150	120	90	150	+
Feather meal	50	70	50	70	70	+
Wheat	100	100	110	130	100	+
Fish oil, herring	120	110	120	110	130	+
Poultry Fat	60	60	60	60	50	+

Unit: kg/tonne of feed

Growth and Feed Efficiency of Rainbow Trout Fed the Test Feeds for 16 weeks at 15ºC.

Diet	Initial weight (g/fish)	Final weight (g/fish)	Weight gain (g/fish)	Feed intake (g/fish)	FE (gain/feed intake)	TGC (%)
MM10	15.5	205	189.2	180.1	1.05[b]	0.199
MM20	15.5	193	177.3	158.4	1.12[ab]	0.192
HM10	15.4	203	187.5	161.0	1.16[ab]	0.199
HM20	15.8	222	206.4	171.7	1.20[a]	0.208
NFM	16.0	208	192.1	182.2	1.06[b]	0.199
Profishent	15.9	203	187.5	165.3	1.13[ab]	0.197
SEM		6.2	6,2	5.2	0.03	0.03

[1] Values with different subscript letters are significantly different ($P<0.05$)

No fish meal, main protein source = poultry by-products meal (40%)

Processing Conditions Affects the Nutritive Value of Processed Animal Proteins

Blood Meal

Guelph System	ADC	
	Protein	Energy
Spray-dried blood meal	96-99%	92-99%
Ring-dried blood meal	85-88%	86-88%
Steam-tube dried blood meal	84%	79%
Rotoplate dried blood meal	82%	82%

Bureau et al. (1999)

Different drying equipments can greatly affect apparent digestibility

Exploring the value of a *in vitro* pH-stat digestibility assay

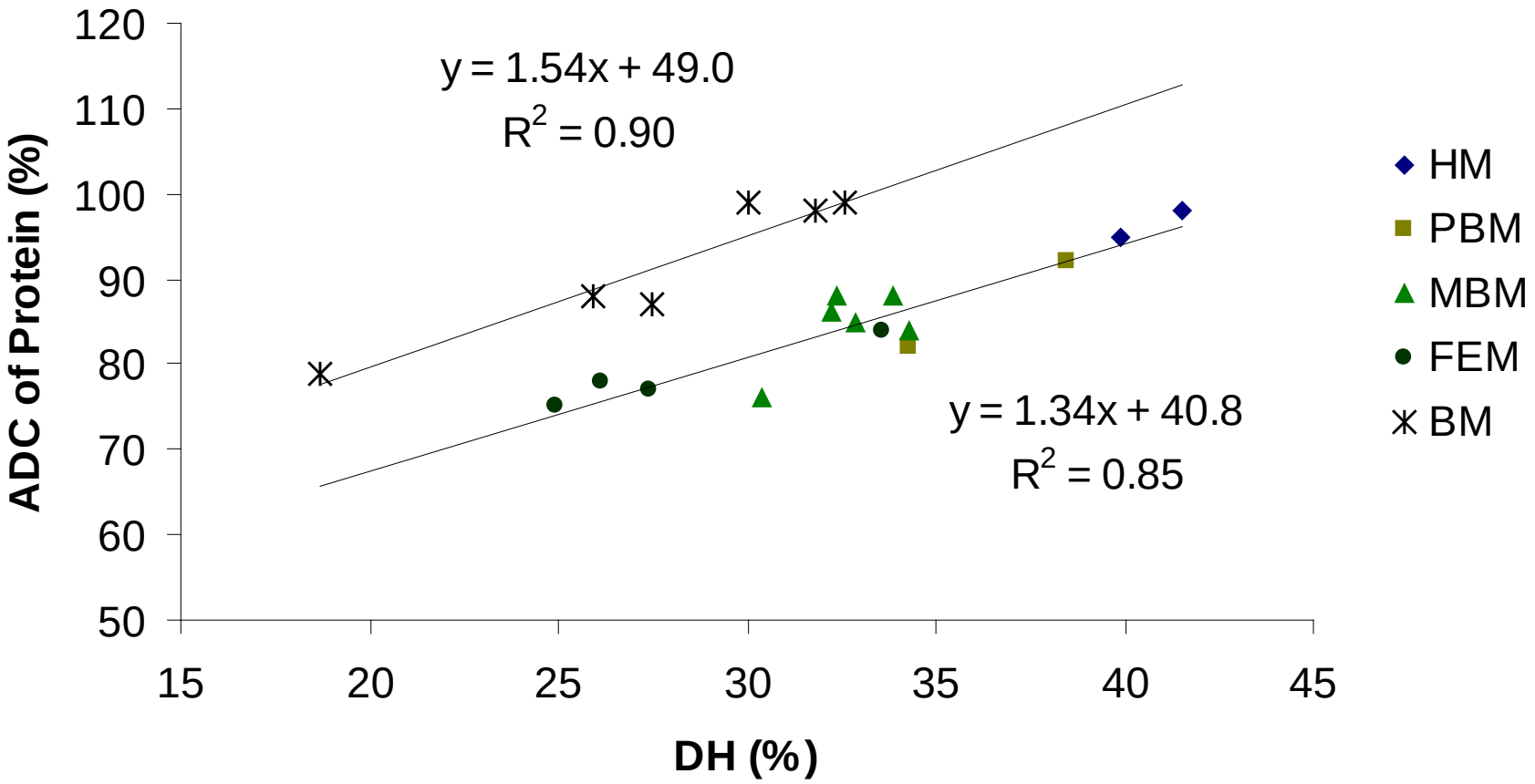
Collaboration with Dr. Adel El Mowafi, Shur-Gain AgResearch

Automated Titrator

TitraLab 854 pH-Stat
Titration Workstation

http://www.labsearch.ie/prod_pages/radiometer/TitraLab/ti_index.html#article1

Relationship between degree of hydrolysis (DH) with pH-Stat assay and digestibility of protein (ADC of protein) of animal proteins.



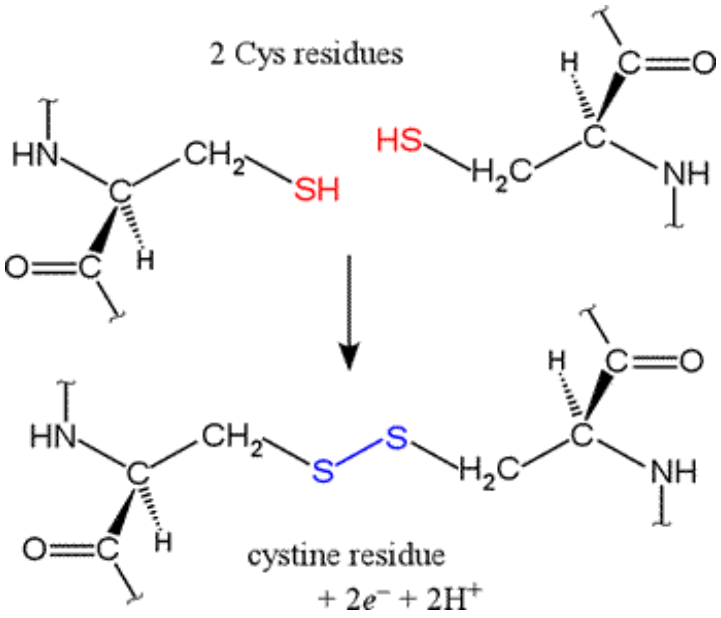
Legends: HM= herring meal, PBM= poultry by-products meal, MBM = meat and bone meal, FEM=feather meal, BM = blood meal

El Mowafi et al.

Feather Meal

Disulfide Bonds

Certain natural proteins, such as keratins, contain many disulfide bonds. These bonds are very stable. Moist heat + pressure can break disulfide bonds



Raw feather and hair (>90% keratins)
Apparent digestibility coefficient of CP= 0%

Feather, steam hydrolyzed (steam + pressure)
Apparent digestibility coefficient of CP > 70%

Different processing conditions can affect digestibility:

-Variations in ADC of crude protein of up to 15% between feather meal processed using different conditions in poultry (Latshaw *et al.,* 1994; Moritz and Latshaw, 2001)

-Fine balance between sufficient hydrolysis and over-processing

FNRL

Apparent Digestibility of Feather Meals from Various Origins to Rainbow Trout

	Processing Conditions (provided by manufacturers)	ADC		
		DM	CP	GE
			%	
1	Steam hydrolysis, 30 min at 276 kPa, disc dryer	82	81	80
2	Steam hydrolysis, 5 min at 448 kPa, disk dryer	80	81	78
3	Steam hydrolysis, 40 min at 276 kPa, ring dryer	79	81	76
4	Steam hydrolysis, 40 min at 276 kPa, steam-tube dryer	84	87	80

Different drying equipments can greatly affect apparent digestibility

Bureau et al. (1999)

Limitations of Apparent Digestibility as a Measure of Nutritive Value

Apparent digestibility is a measure of “disappearance” of nutrients but not a direct measure of the amount of nutrient available

Heat damaged amino acids may be digestible but not available

Should validate estimate of digestibility with more direct assessment of the bioavailability of nutrients in feed ingredients

Formulation of Experimental Diets Used in Feather Meal Trial

Ingredients	Diet							
	1	2	3	4	5	6	7	8
Herring meal	50	35	35	35	50	40	30	20
Blood meal, tube-dried	10	10	10	10	6	9	12	15
Feather meal 1		15						
Feather meal 2			15					
Feather meal 4				15	8	12	16	20
Corn gluten meal	10	10	10	10	6	9	12	15
Whey	12	12	12	12	12	12	12	12
Vitamins + minerals	3	3	3	3	3	3	3	3
Fish oil	15	15	15	15	15	15	15	15

Performance of rainbow trout fed diets with different feather meals

Diet	Gain g/fish	Feed g/fish	FE G:F	RN g/fish	RE kJ/fish
1- Control	73.5 ab	51.6	1.42 ab	1.9 a	587 a
2- 15% FEM 1	74.3 ab	51.4	1.44 a	1.9 a	553 a
3- 15% FEM 2	71.1 bc	52.0	1.37 bc	1.8 a	561 a
4- 15% FEM 4	73.0 abc	52.3	1.40 abc	1.9 a	547 a
5- 20% FEM-CGM-BM	74.5 a	51.8	1.44 a	1.9 a	574 a
6- 30% FEM-CGM-BM	73.2 abc	51.7	1.42 abc	1.9 a	554 a
7- 40% FEM-CGM-BM	73.3 abc	52.2	1.41 abc	1.9 a	579a
8- 50% FEM-CGM-BM	70.1 c	51.8	1.35 c	1.8 a	537a

Could not highlight differences in the nutritive value of feather meals with different digestible protein levels. Diets 2-4 contained at least 35% fish meal.

Slope Ratio Assay

- Response of parameter of interest, e.g. protein gain, to graded levels of test ingredient is compared to that of graded levels of standard source of nutrient of interest (e.g. synthetic amino acid)

- Indicates the net effect of all components that can affect bioavailability (digestion, absorption and utilization).

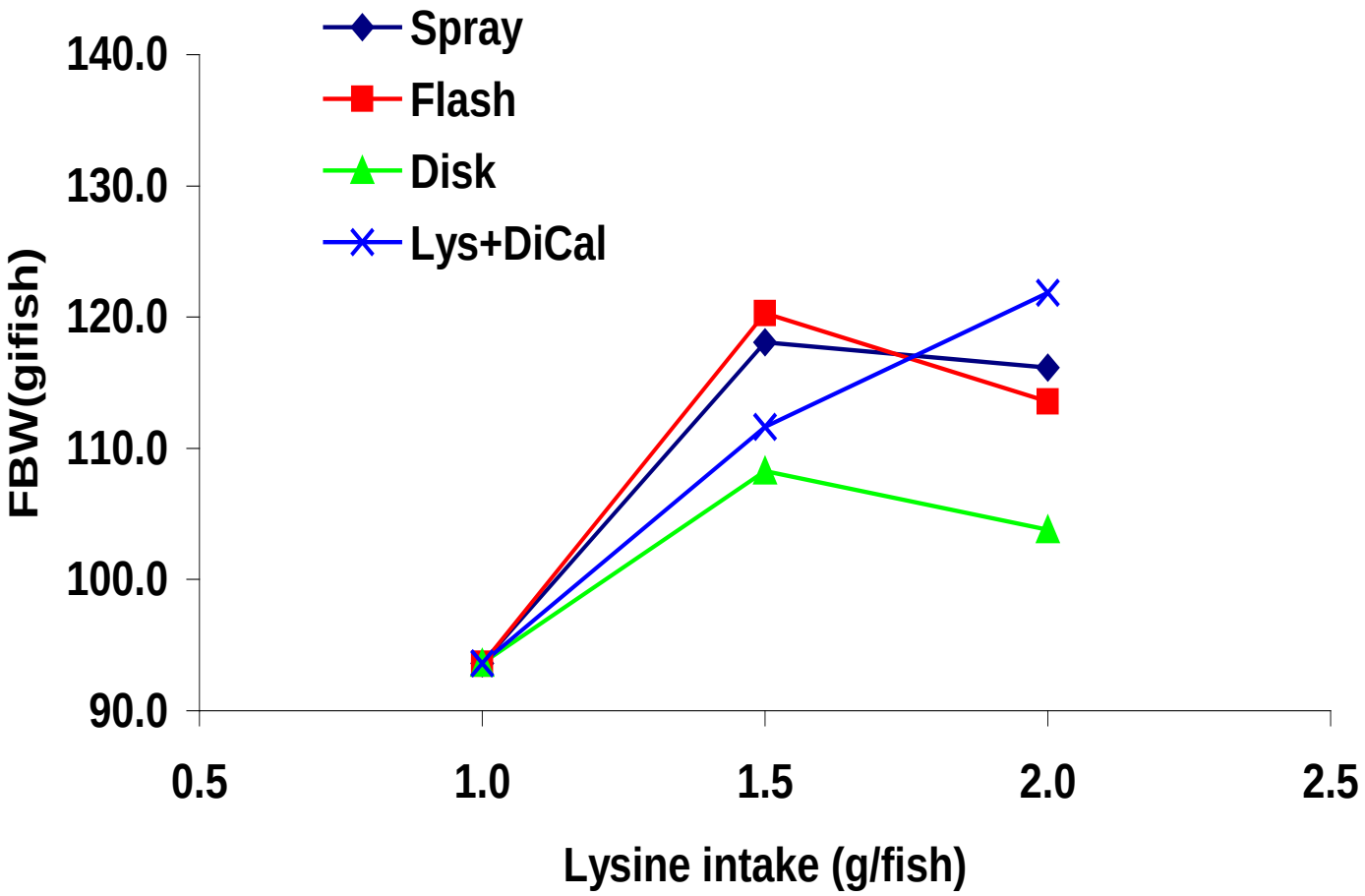
Blood Meal

Guelph System	ADC	
	Protein	Energy
Spray-dried blood meal	96-99%	92-99%
Ring-dried blood meal	85-88%	86-88%
Steam-tube dried blood meal	84%	79%
Rotoplate dried blood meal	82%	82%

Bureau et al. (1999)

Different drying equipments can greatly affect apparent digestibility

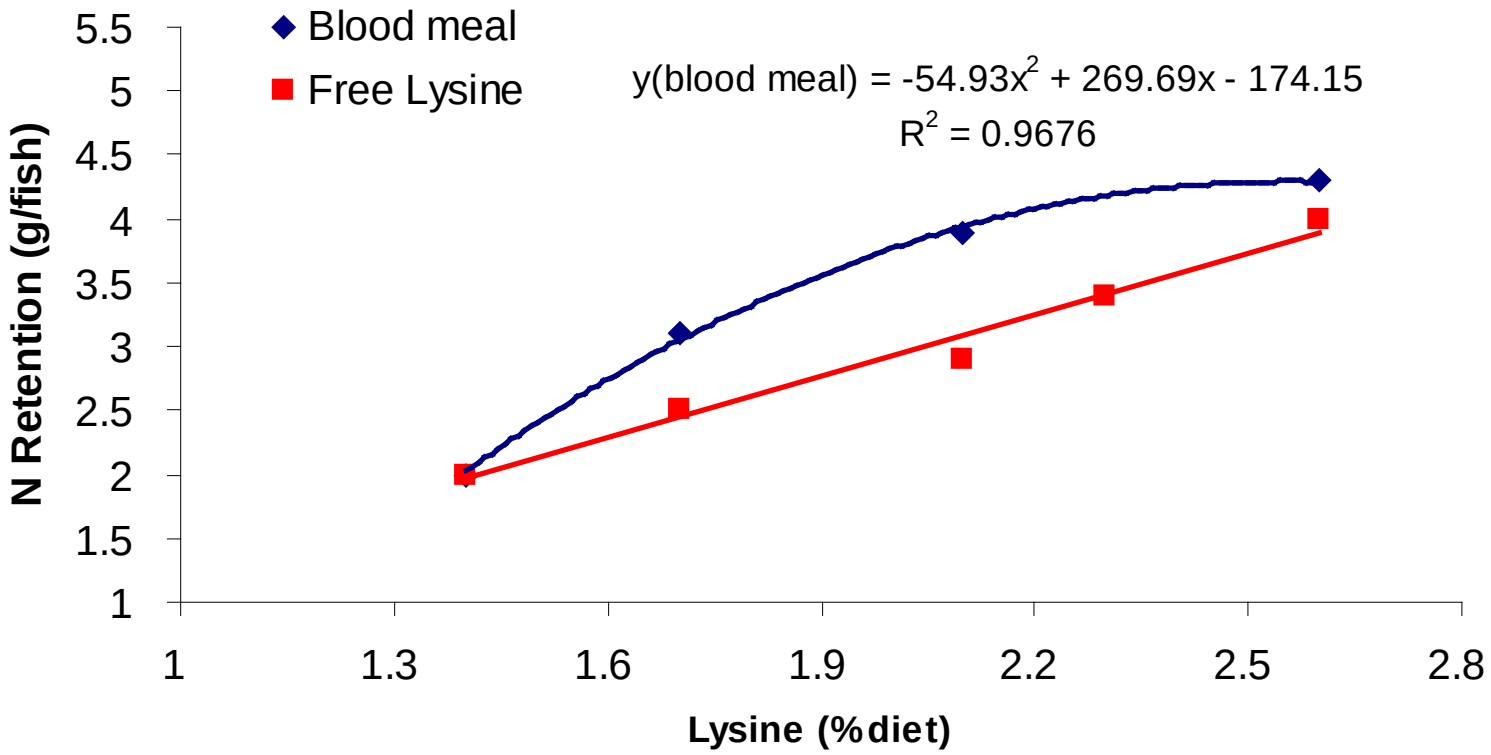
Final Body Weight - Lysine Bio-Availability Trial



Shows that differences exist in the bioavailability of lysine in blood meals produced with different drying equipment

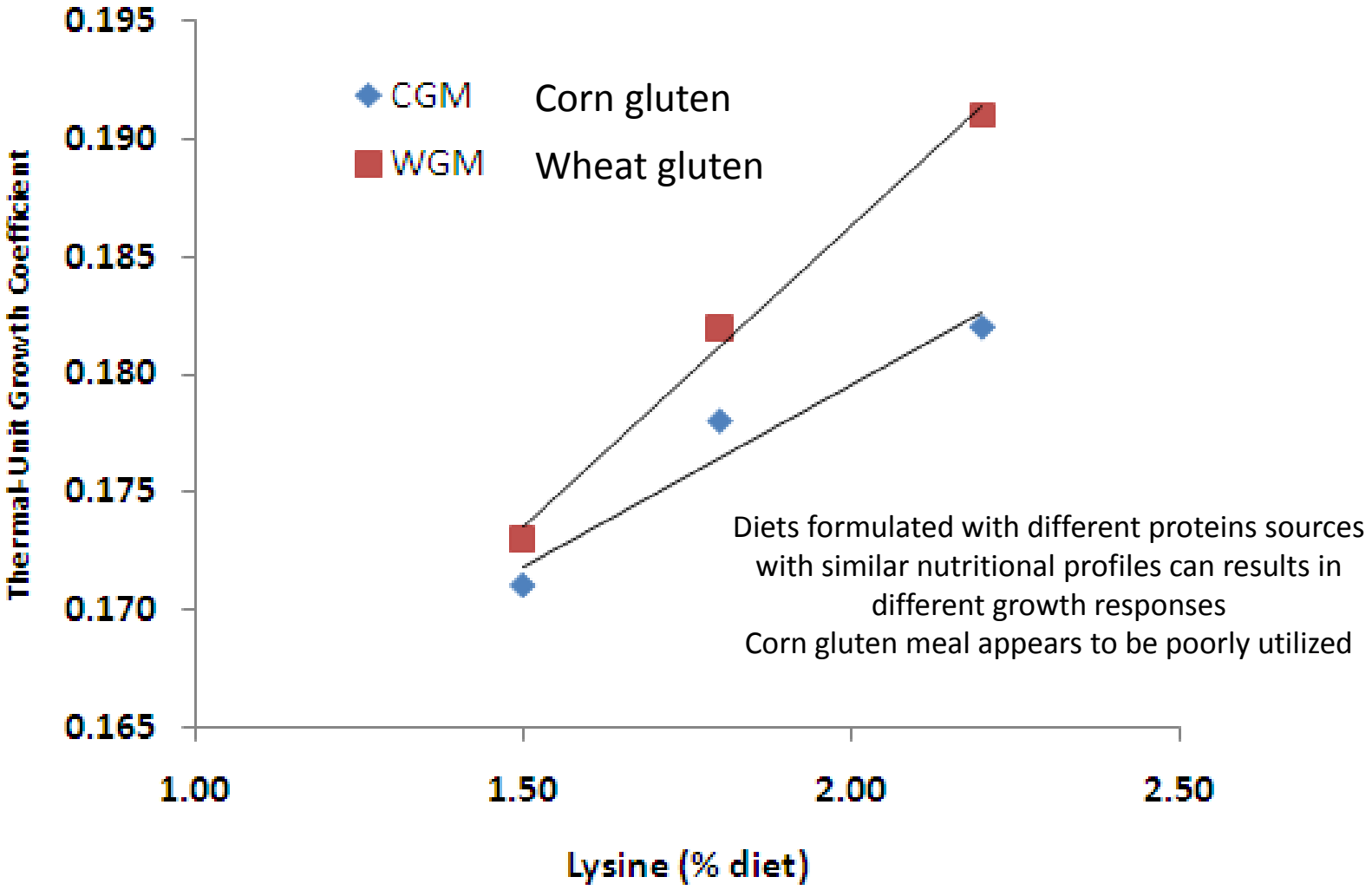
El Haroun and Bureau (2006)

N gain of rainbow trout fed lysine deficient basal diet supplemented with free L-Lysine or spray-dried blood meal (two sources of "highly digestible" lysine).



Digestible lysine from high quality blood meal is apparently of slightly higher bioavailability (bio-efficacy) than crystalline L-Lysine

Effect of graded levels of L-lysine (Biolys®) in corn gluten meal (CGM) or wheat gluten meal (WGM) based diets fed to **rainbow trout for 8 weeks.**



Diets formulated with different proteins sources with similar nutritional profiles can results in different growth responses
Corn gluten meal appears to be poorly utilized

Gholami et al. (in progress)

Apparent Digestibility of Feather Meals from Various Origins to Rainbow Trout

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		DM	CP	GE
			%	
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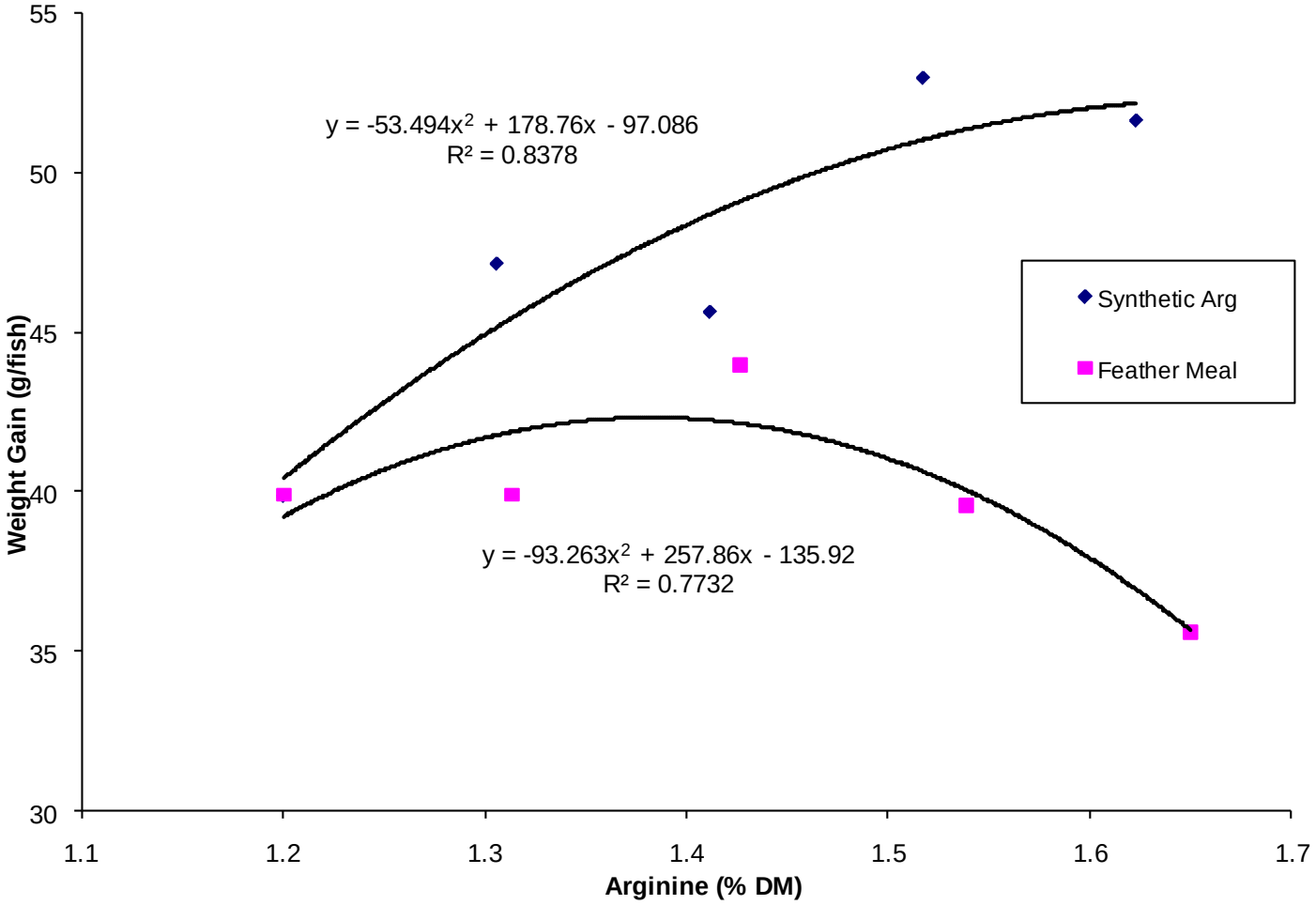
2	Steam hydrolysis, 5 min at 448 kPa, disk dryer	80	81	78
3	Steam hydrolysis, 40 min at 276 kPa, ring dryer	79	81	76
4	Steam hydrolysis, 40 min at 276 kPa, steam-tube dryer	84	87	80

Bureau et al. (1999)

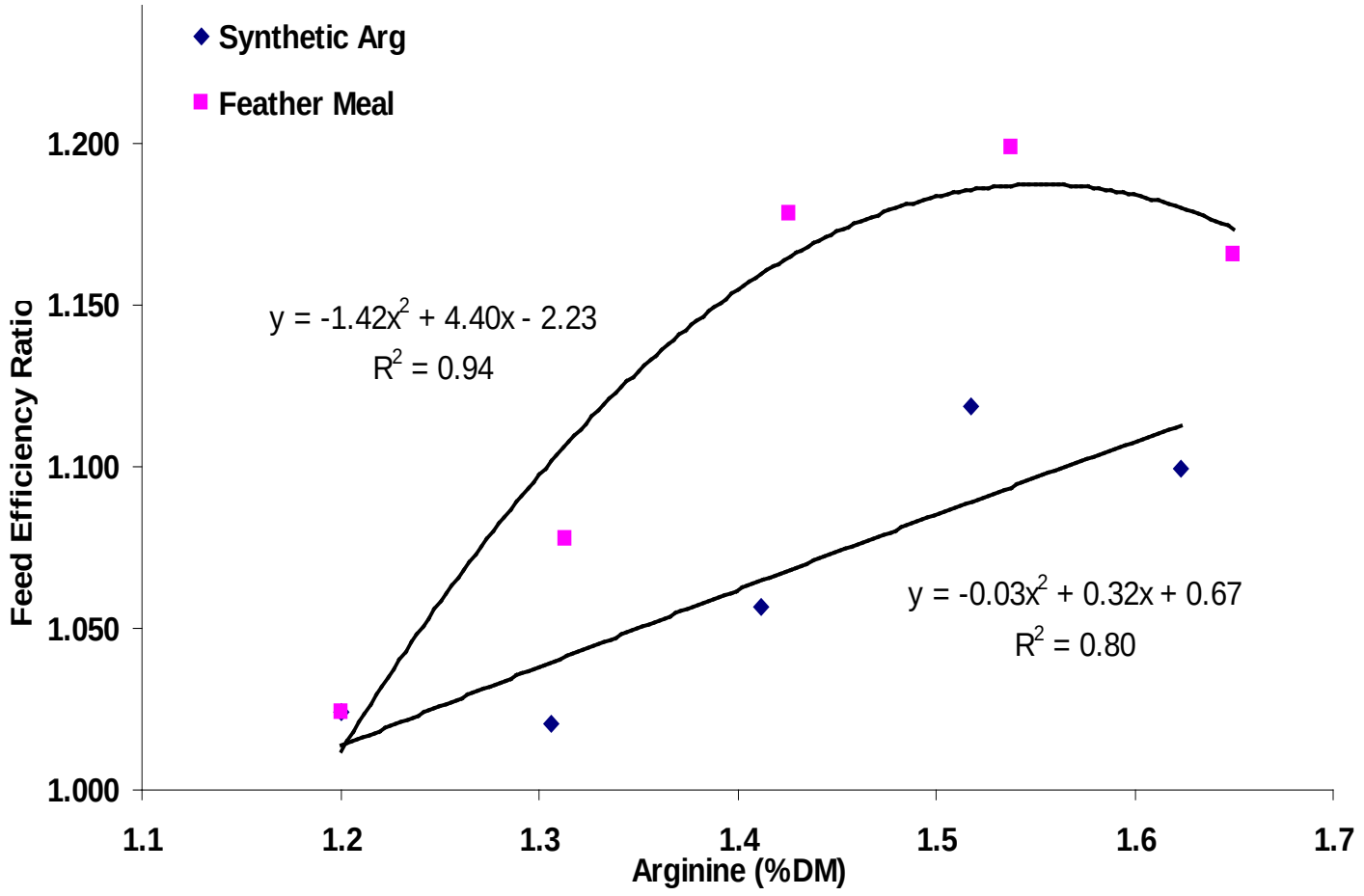
Trial #1 – Bioavailability of Arginine in Feather Meal using a Slope-Ratio Assay - Formulation of the Experimental Diets

Ingredient	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Diet 7	Diet 8	Diet 9
Skim milk powder	20	20	20	20	20	18	16	14	12
Corn gluten meal	32	32	32	32	32	28	24	20	16
L-arginine		0.1	0.2	0.3	0.4				
Feather meal						6	12	18	24
Calculated Composition (% DM)									
CP	40.3	40.4	40.5	40.6	40.7	40.6	40.8	41.0	41.2
Lipid	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.1
Arg (digestible)	1.19	1.30	1.40	1.51	1.61	1.31	1.42	1.53	1.64

Trial 1 - Weight gain of rainbow trout in response to increase dietary arginine supplied as L-arginine or feather meal



Trial 1 - Feed efficiency (gain:feed) in response to increase dietary arginine supplied as L-arginine or feather meal



Trial #1 – Bioavailability of Arginine in Feather Meal using a Slope-Ratio Assay - Digestible amino acid composition of the diets

Diet	Arg	Lys	Met + Cys	Thr	Phe +Tyr	**His**	Val	Leu	Ile
1 Basal	1.2	2.9	1.8	1.5	3.9	**1.1**	1.7	4.8	1.5
2 Arg	1.3	2.9	1.8	1.5	3.9	**1.1**	1.7	4.8	1.5
3 Arg	1.4	2.9	1.8	1.5	3.9	**1.1**	1.7	4.8	1.5
4 Arg	1.5	2.9	1.8	1.5	3.9	**1.1**	1.7	4.8	1.5
5 Arg	1.6	2.9	1.8	1.5	3.9	**1.1**	1.7	4.8	1.5
6 FEM	1.3	2.9	1.8	1.6	3.6	**1.0**	1.8	4.5	1.5
7 FEM	1.4	2.8	1.8	1.6	3.4	**1.0**	1.9	4.2	1.5
8 FEM	1.5	2.8	1.9	1.6	3.2	**0.9**	2.0	3.9	1.5
9 FEM	1.7	2.7	1.9	1.7	2.9	**0.8**	2.0	3.6	1.5
Requirements:									
NRC (1993)	1.5	1.8	1.0	0.8	1.8	**0.7**	1.2	1.4	0.9

Trial #2 – Supplementation of Trial #1 Diets with various EAA supplements

Diet	Original Diet – Trial #1	Supplement	Weight gain g/fish
1	Diet 1 – 1.3% Arginine	None	64.1
2	Diet 4 -1.6% Arg, (L-Arg)	None	75.5
3	"	+ 0.5% DL Methionine	68.0
4	"	+ 4% EAA mix (no Met, no Arg)	73.1
5	"	+ 4% EAA + 0.5% DL Met	65.1
6	Diet 8 – 2.1% Arg (24% FEM)	None	72.3
7	"	+ 0.5% DL Methionine	68.2
8	"	+ 4% EAA mix (no Met, no Arg)	**81.2***
9	"	+ 4% EAA + 0.5% DL Met	74.5

* Significant different from unsupplemented diet (Diet 6)

Observations – Trials with Feather Meals

Fish fed basal dietsupplemented with L-arginine responded well (normal response)

Weight gain of fish fed feather meal did not respond to arginine levels.

Interestingly, feed efficiency (and energy retention) improved very significantly with increasing level of feather meal. This means that overall, the nutrients (amino acids / energy) in feather meal were well utilized by the animal

Experimental diets formulated to meet all essential amino acid requirements according to NRC (1993) levels with large safety margin for all essential amino acids. Obviously overlooked something. May be one or two essential amino acids are VERY poorly available.

NRC estimates of amino acid requirements need to be revisited
e.g. FEM diets apparently 15-30% above His requirement but still no response

Supplementation feather meal diets with various essential nutrients to find out which one likely missing.

Predicting the Digestible Phosphorus Content of Fish Feeds:

Value of a Nutritional Modeling Approach

P Content of Common Fish Feed Ingredients

Ingredients	P content (%)
Fish meal	1.08 – 4.19
Meat and bone meal	2.49 – 7.08
Poultry by-product meal	1.65 – 3.45
Blood meal	0.08 – 1.71
Feather meal	0.54 – 1.26
Corn gluten meal	0.44 – 0.55
Soybean meal	0.64 – 0.85
Wheat middling	0.97 – 1.17

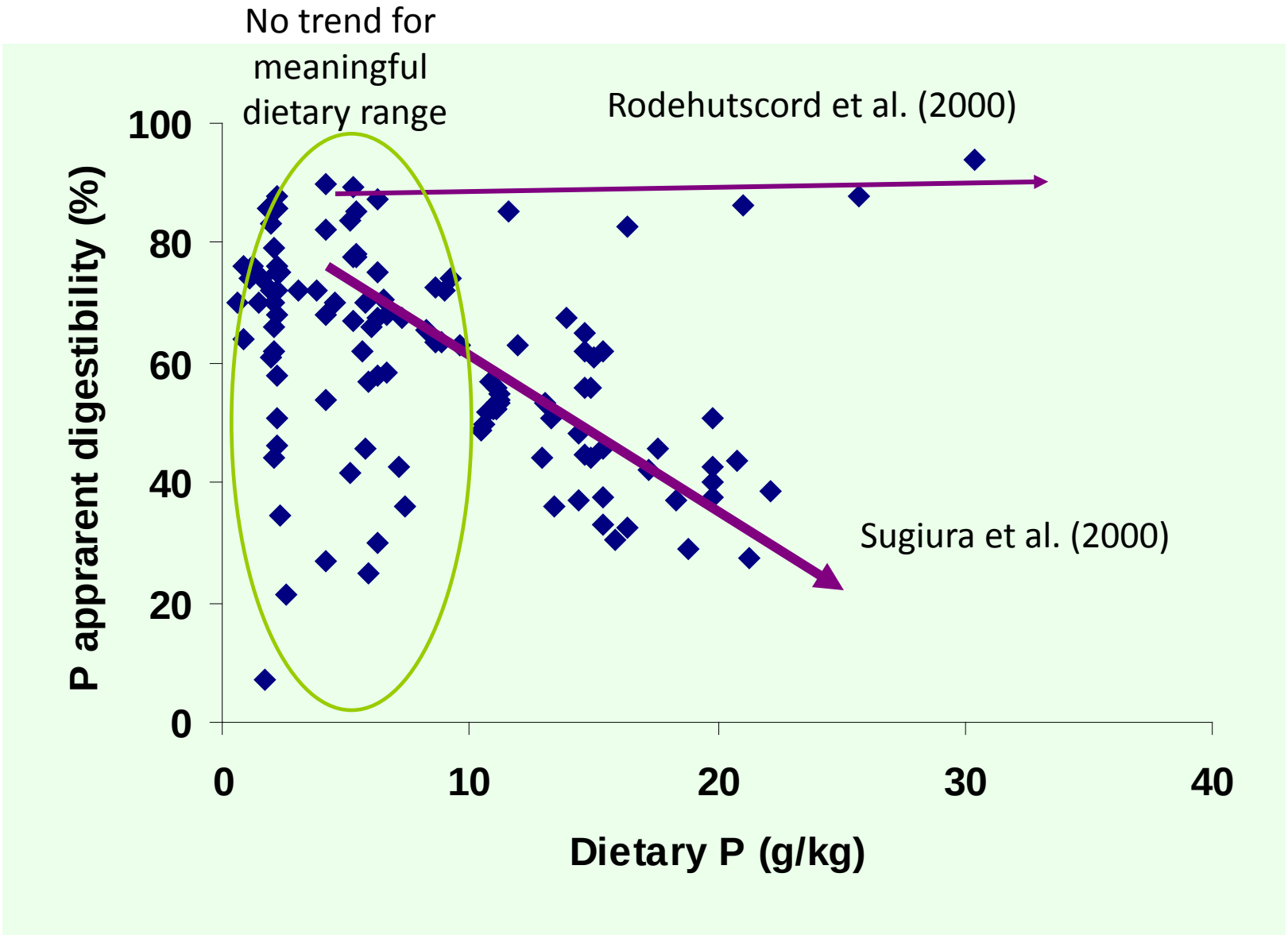
Summarized from various sources in literature

Estimates of Apparent Digestibility Coefficient (ADC) of P in Salmonids feed Ingredients

Ingredient	ADC (%)
Fish meal	17 - 81
Meat and bone meal	22 - 67
Poultry by-products meal	38 - 66
Feather meal	68 - 82
Blood meal	70 - 104
Soybean meal	27 - 46
Corn gluten meal	<10
NaH_2PO_4	95 - 98
$Ca(H_2PO_4)_2$	90 - 94
$CaHPO_4$	54 - 77
$Ca_{10}(OH)_2(PO4)_6$ or $Ca_3(PO_4)_2$	37 - 64

Summarized from various sources in literature

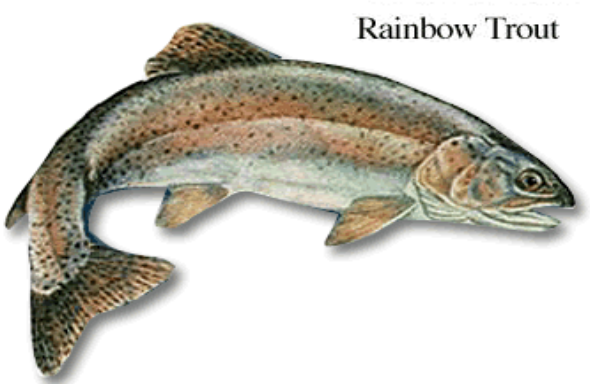
Dietary Phosphorus Digestibility



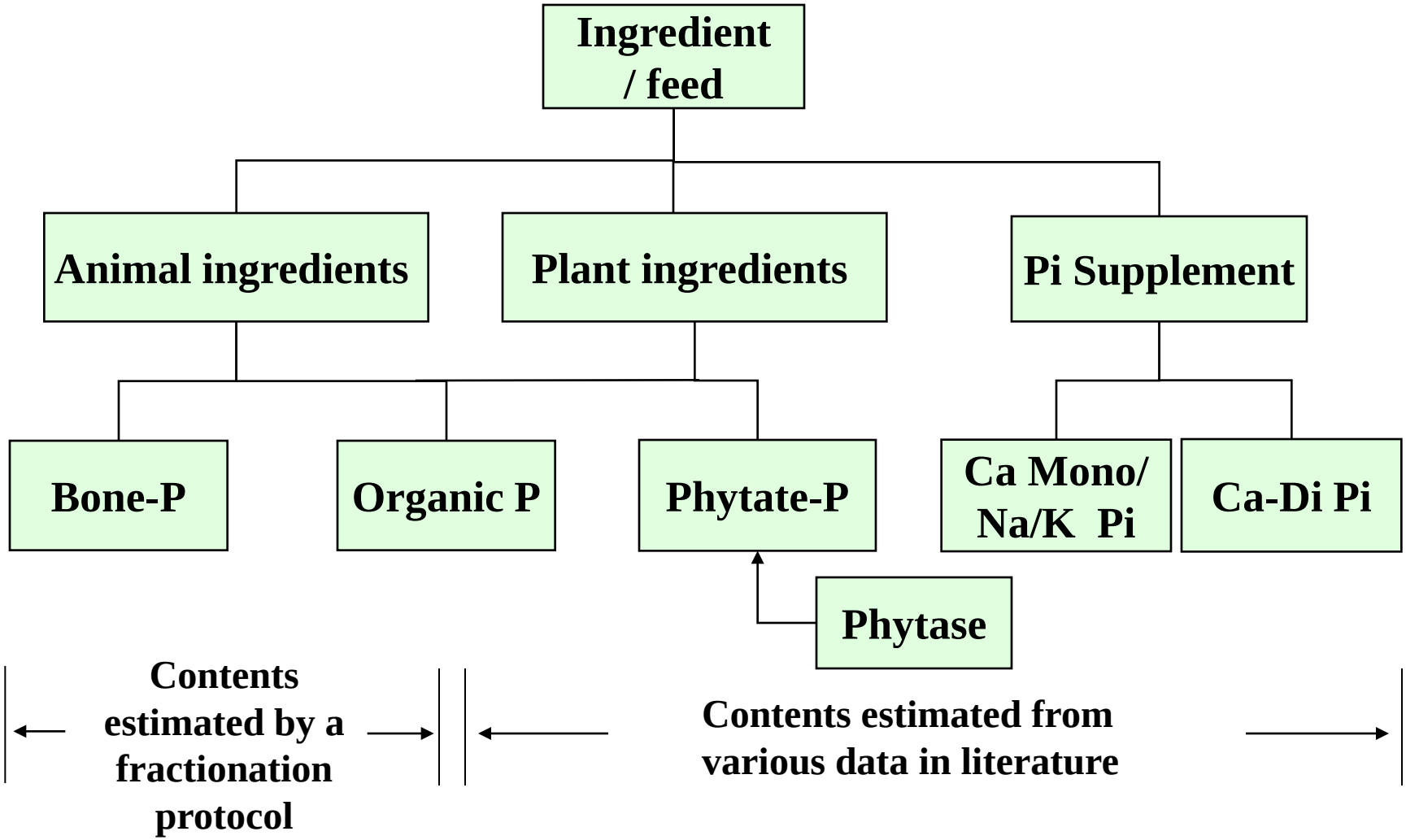
137 treatments from 22 studies with rainbow trout

A Model to Estimate P Digestibility

(Hua and Bureau 2006)



Classification and Content of P Compounds

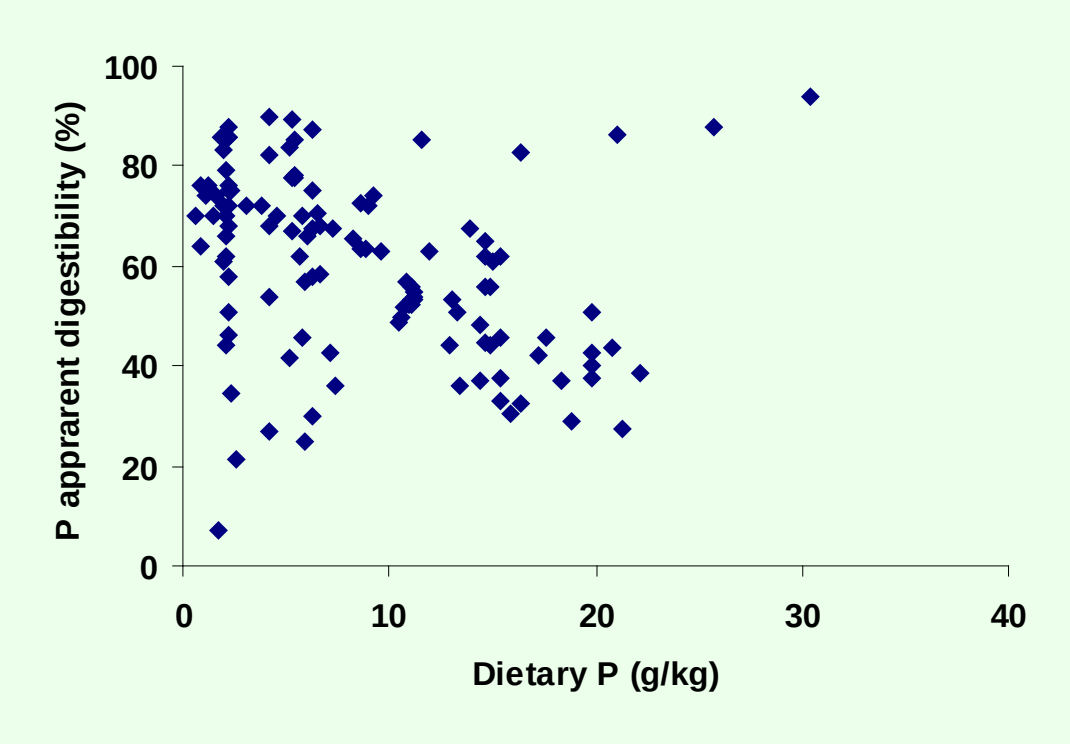


P Digestibility Model

- Dataset: 137 treatments from 22 studies with rainbow trout
- Multiple Regression Approach

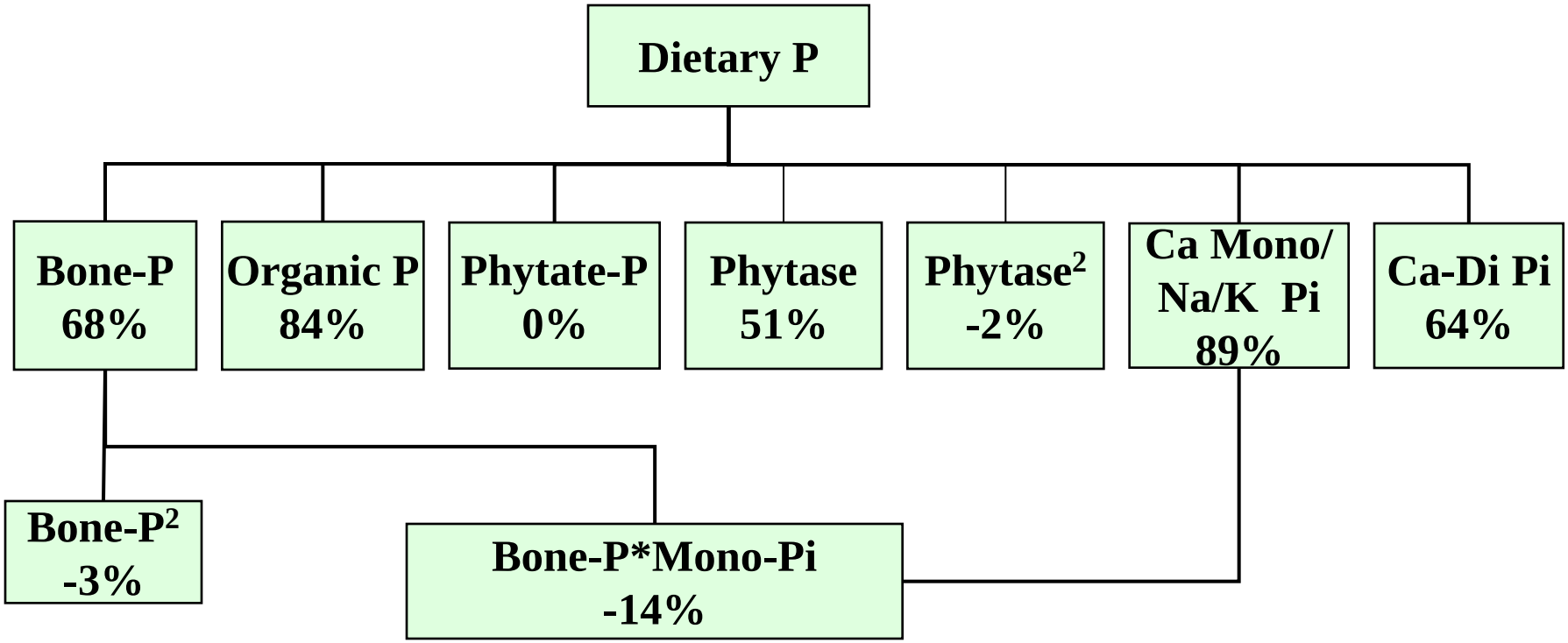
  Digestible P content

  = Σ digestibility of P compounds * inclusion level of P compounds



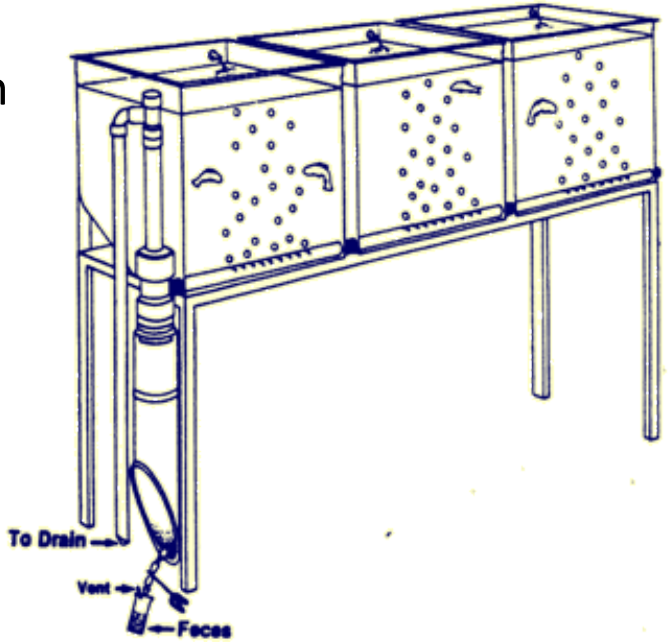
Hua and Bureau (2006)

Results: Parameter Estimates From Multiple Regression



Experimental Validation by Digestibility Trial

- Digestibility trial conducted with the Guelph system using the protocol of Cho et al. (1982)
- Reference diet:
  - Fish meal/corn gluten meal-based diet
- Test diets:
  - 2 fish meals (high vs. low ash)
  - 1 meat and bone meal
  - 2 poultry by-products meals (high vs. low ash)
  - 2 soy protein concentrates (regular vs. dephytinized)



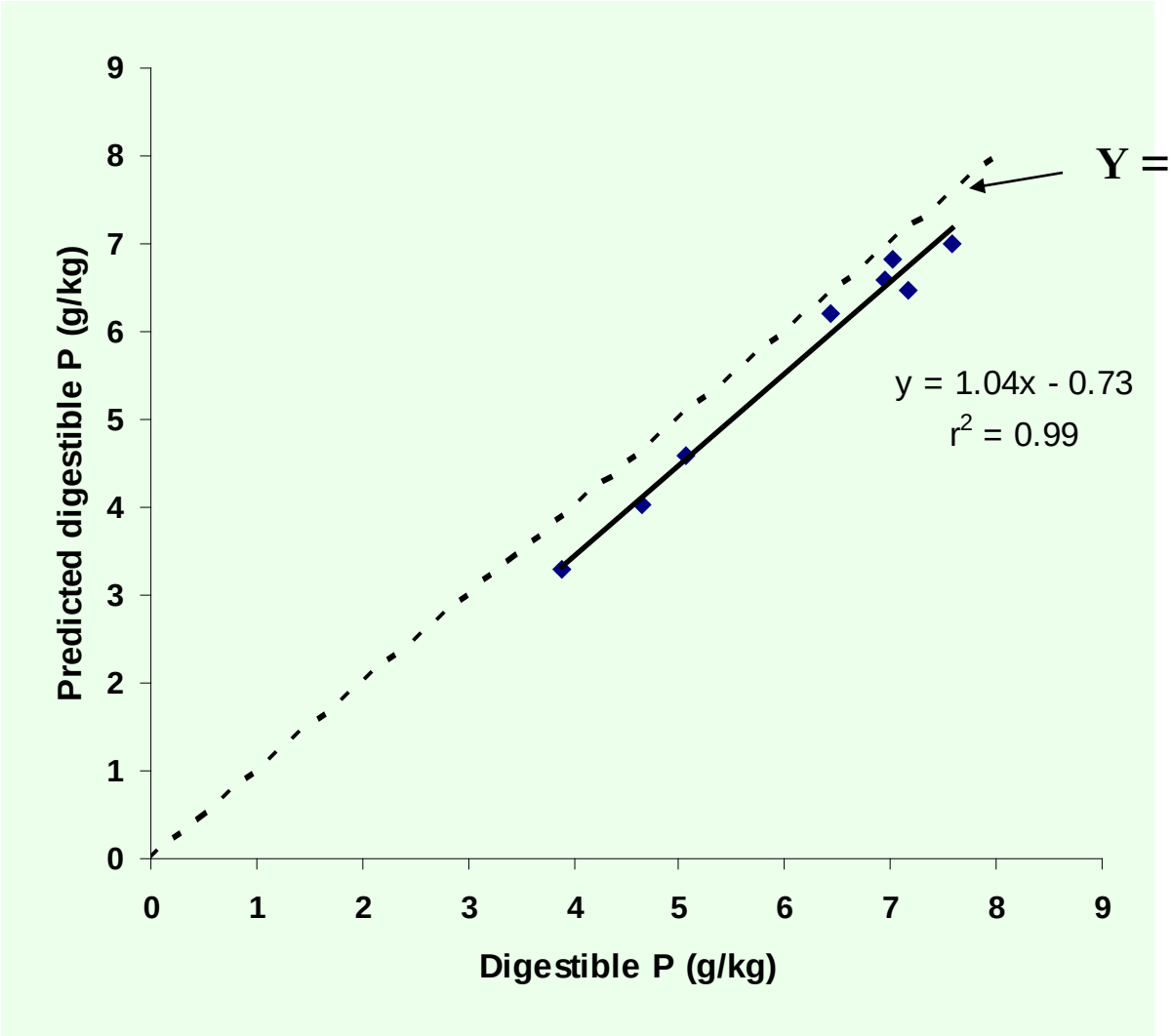
Hua and Bureau (2006)

Levels of Total P and Different P Chemical Forms in Experimental Diets

Diet No.	Diet	Total P	Bone P	Phytate P	Organic P
1	Reference diet	7.3	2.9	2.6	1.8
2	Herring meal diet	12.0	6.3	1.9	3.8
3	Menhaden meal diet	13.7	8.0	2.0	3.8
4	Meat and bone meal diet	14.6	8.7	1.9	3.9
5	Low ash PBM diet	12.6	6.7	1.9	4.0
6	Regular PBM diet	14.5	8.4	1.9	4.2
7	Soy Protein Concentrate	8.7	3.1	3.1	2.6
8	Dephytinized SPC	8.5	3.0	2.2	3.3

Units: g/kg DM

Results of Experimental Validation



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